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Plutonium/High Level Vitrified Waste - DBE Offsite Dose Calculation

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FIGURES

TABLES

1. PURPOSE

The purpose of this calculation is to provide a bounding dose consequence analysis of the immobolized plutonium (can-in-canister) waste form to be handled at the Monitored Geologic Repository (MGR) at Yucca Mountain. The current concept for the Plutonium Can-in-Canister waste form is provided in Attachment III. A typical design basis event (DBE) defines a scenario that generally includes an initiating event and the sequences of events that follow. This analysis will provide (1) radiological releases and dose consequences for a postulated, bounding DBE and (2) design-related assumptions on which the calculated dose consequences are based. This analysis is part of the safety design basis for the repository. Results will be used in other analyses to determine or modify the safety classification and quality assurance level of repository structures, systems, and components (SSCs).

The Quality Assurance (QA) program applies to this calculation. The work reported in this document is part of the analysis of MGR DBEs and is performed using AP-3.12Q, *Calculations*. The work done for this analysis was evaluated according to QAP-2-0, *Control of Activities*. This evaluation determined that such activities are subject to DOE/RW/0333P, *Quality Assurance Requirements and Description* (DOE 1998), requirements. This calculation is quality affecting because the results may be used to support analyses of repository SSCs per QAP-2-3, *Classification of Permanent Items*.

2. METHOD

The calculations described in this document are made with equations solved in Excel 97 spreadsheets. Performing the calculations in spreadsheets offers several advantages: (1) dose estimates are easily understood since calculations are easily checked, (2) the calculations for release, transport, mitigation, and dispersion are easily combined into one electronic document, and (3) dose sensitivity studies can be easily performed.

The equations described in this section are used to calculate:

- Source Terms
- Inhalation and Air Submersion Dose Calculations, and
- Committed Dose Equivalent (CDE), Deep Dose Equivalent (DDE), Committed Effective Dose Equivalent (CEDE), and Total Effective Dose Equivalent (TEDE) Calculations.

2.1 SOURCE TERMS

The source term released to the environment by a postulated DBE from the Pu waste in a Pu can-in-canister canister is calculated using equation (1) (DOE 1994, p. 1-2).

$$ST_{j,Pu} = MAR_{j,Pu} \times DR_{j,Pu} \times ARF_{j,Pu} \times RF_{j,Pu} \times LPF_{j,Pu} \qquad (1)$$

where,

$ST_{j,Pu}$ - the amount of the j^{th} isotope in the Pu waste that is released to the environment per canister [Ci/canister]

$MAR_{j,Pu}$ - the "material-at-risk" of the j^{th} isotope in the Pu waste per canister [Ci/canister]

$DR_{j,Pu}$ - the fraction of the j[th] isotope in the "material-at-risk" that is affected by the DBE (i.e., the damage ratio) [unitless]

$ARF_{j,Pu}$ - the airborne release fraction of the j[th] isotope applicable to the DBE [unitless]

$RF_{j,Pu}$ - the respirable fraction of the j[th] isotope applicable to the DBE [unitless]

$LPF_{j,Pu}$ - the leak path factor of the j[th] isotope applicable to the DBE [unitless].

2.2 INHALATION AND SUBMERSION DOSE CALCULATIONS

The inhalation dose to an individual from each isotope in the source term from the Pu waste per Pu can-in-canister canister is calculated using equation (2) per Regulatory Guide 1.109.

$$D_{j,k,Pu}^{inh} = ST_{j,Pu} \times \frac{\chi}{Q} \times BR \times conv \times DCF_{j,k}^{inh} \qquad (2)$$

While the air submersion dose is calculated using equation (3). Note that source term, ST, has been modified by dividing out the respirable fraction, RF, in equation (3) since the air submersion dose should not be modified by the fraction of the source material that is respirable.

$$D_{j,k,Pu}^{sub} = \frac{ST_{j,Pu}}{RF_{j,Pu}} \times \frac{\chi}{Q} \times conv \times DCF_{j,k}^{sub} \qquad (3)$$

where,

$D_{j,k,Pu}^{inh}$ - radiation dose from the j[th] isotope of the Pu waste to the k[th] "organ" due to inhalation [rem]

$D_{j,k,Pu}^{sub}$ - radiation dose from the j[th] isotope of the Pu waste to the k[th] "organ" due to air submersion [rem]

k - "organ" index, where "organs" are gonads, breast, lungs, red marrow, bone surface, thyroid, remainder, effective, and skin [unitless]

$\frac{\chi}{Q}$ - atmospheric dispersion factor [s/m^3]

BR - breathing rate [m^3/s]

$DCF_{j,k}^{inh}$ - the inhalation dose conversion factor of the j[th] isotope for the k[th] organ [Sv/Bq]

$DCF_{j,k}^{sub}$ - the submersion dose conversion factor of the j[th] isotope for the k[th] organ [(Sv m^3)/(Bq s)]

$conv$ - DCF unit conversion factor: 3.7×10^{12} (rem Bq)/(Ci Sv) = 3.7×10^{10} (Bq)/(Ci) x 100 (rem/Sv) (Eckerman et al. 1988, p. 121).

The total inhalation dose to an individual from each isotope in the Pu and HLW source terms in the Pu can-in-canister is calculated by equation (4).

$$D_{j,k}^{inh} = D_{j,k,Pu}^{inh} + (1-x)D_{j,k,HLW}^{inh} \qquad (4)$$

While the air submersion dose is calculated using equation (5).

$$D_{j,k}^{sub} = D_{j,k,Pu}^{sub} + (1-x)D_{j,k,HLW}^{sub} \quad (5)$$

where,

$D_{j,k,HLW}^{inh}$ - radiation dose from the j[th] isotope of the HLW to the k[th] "organ" due to inhalation [rem]

$D_{j,k,HLW}^{sub}$ - radiation dose from the j[th] isotope of the HLW to the k[th] "organ" due to air submersion [rem]

x - the fraction of the Pu can-in-canister canister that is Pu waste [unitless]

$D_{j,k}^{inh}$ - radiation dose from the j[th] isotope of all the waste in a Pu can-in-canister canister to the k[th] "organ" due to inhalation [rem]

$D_{j,k}^{sub}$ - radiation dose from the j[th] isotope of all the waste in a Pu can-in-canister canister to the k[th] "organ" due to air submersion [rem].

The HLW doses per HLW canister are obtained from the *High-Level Vitrified Waste Dose Calculation* (CRWMS M&O 1999, Attachment VII-1).

2.3 CDE, DDE, CEDE, AND TEDE CALCULATIONS

The Committed Dose Equivalent (CDE), the Deep Dose Equivalent (DDE), the Committed Effective Dose Equivalent (CEDE), the Total Effective Dose Equivalent (TEDE), and the dose equivalent to the lens of the eye, the skin and extremities are calculated. The equations used to produce these dose equivalents in terms of the radiation doses calculated in Section 5.3 are shown here.

The TEDE and the CDE + DDE dose measures, ignoring the ingestion dose pathway [Assumption 3.5], are expressed as:

$$TEDE = CEDE + DDE = \sum_j D_{j,effective}^{inh} + \sum_j D_{j,effective}^{sub} \quad (6)$$

$$CDE_k + DDE = \sum_j D_{j,k}^{inh} + \sum_j D_{j,effective}^{sub} \quad \text{where } k \neq \text{effective or skin} \quad (7)$$

where,

$TEDE$ - total effective dose equivalent [rem]

$CEDE$ - committed effective dose equivalent [rem]

DDE - deep dose equivalent [rem]

CDE_k - committed dose equivalent to the k[th] organ [rem].

The skin and extremities dose is expressed as:

$$SKIN = \sum_j D_{j,skin}^{sub} \tag{8}$$

where,

$SKIN$ - dose to the skin & extremities [rem].

3. ASSUMPTIONS

3.1 A restricted area boundary of 5,000 meters will be established around the Waste Handling Building (WHB). This assumption is the basis for selection of a 5,000-meter distance for estimating atmospheric dispersion factors. *Basis:* This value is based on the restricted area boundary established in the *MGR Requirements Document* (YMP 1999, Section 3.3.J). *Usage:* This assumption is used in the off-site dose calculations in Sections 3.3, 5.1, 5.2.3 and 5.2.4.

3.2 It is assumed that during non-mechanistic breach of the Plutonium Can-in-Canister canister, the release of radionuclides occurs within a 2-hour period. *Basis:* This is a conservative assumption for the non-mechanistic release. This approach is consistent with Section C.i of Regulatory Guide 1.25, *Assumptions Used for Evaluating Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors*. *Usage:* This assumption is used in the off-site dose calculations in Section 5.3.

3.3 An adult breathing rate of 3.33×10^{-4} m^3/s (20 liters/min) was assumed for all dose calculations. *Basis:* This is based on the Reference Man breathing rate established in ICRP 23 (ICRP 1974, p. 346). This breathing rate is based on the volume intake of air for "light activity" and is considered to be appropriate for DBE accident scenarios resulting in short-term (≤ 8-hour) exposures to the public at the 5,000-meter site boundary [Assumption 3.1]. The scientific community generally accepts this assumption and has found it to be technically defensible. *Usage:* This assumption is used in the off-site dose calculations in Sections 5.2.4 and 5.3 and Attachment II-6, II-7, II-9, II-11, II-13, II-15 and II-17.

3.4 The atmospheric dispersion factors (χ/Q) are taken from an Inter-Office Correspondence from Walt Schalk and Doug Landwehr to Kelvin Montague, "Preliminary χ/Q Concentration Estimates Using Nuclear Regulatory Commission (NRC) Regulatory Guide 1.145 as Implemented by the XQ145 Software Routine" (Schalk, W. and Landwehr, D. 1998, Table 3). *Basis:* The values were calculated using the methodology outlined in Regulatory Guide 1.145. The maximum values that were exceeded 0.5% of the time were used for dispersion calculations in this report, and are assumed applicable to mechanistic and non-mechanistic events. *Usage:* This assumption is used in the off-site dose calculations in Section 5.2.3.

3.5 Only inhalation and air submersion doses are considered in this calculation; the potential doses from ingestion, water immersion, and contaminated soil are ignored. *Basis:* This assumption implies that these doses are negligible in comparison to the combined inhalation and air submersion dose and/or the receptors at the assumed site boundary are evacuated shortly after the postulated event, thus precluding these source term pathways. *Usage:* This assumption is used in the off-site dose calculations in Sections 2.3 and 5.3.3.

3.6 For isotopes with multiple clearance classes, the lung clearance class that yields the highest inhalation DCF is assumed on a per organ basis. *Basis:* This assumption maximizes the calculated inhalation doses. The DCFs generated by the Environmental Protection Agency are generally accepted by the scientific community and found to be technically defensible. Thus, selecting the largest DCF value on a per organ basis is conservative. *Usage:* This assumption is used in the off-site dose calculations in Section 5.2.5.

3.7 It is assumed that the airborne release fraction (ARF) for plutonium in a can-in-canister canister is equal to 1.6×10^{-3}. This fraction will be applied to the release of all the radionuclides from Pu waste in a DBE that may potentially cause a canister to breach. *Basis:* This assumption is based on brittle fracture studies made on SYNROC, a ceramic material similar to the plutonium ceramic waste form. These studies were performed at Argonne National Laboratory and are reported in ANL (1982) Table 6, page 24. The values are considered conservative because the impact tests on SYNROC were preformed at much higher impact energies than anticipated during a drop of the plutonium can-in-canister at the MGR. *Usage:* This assumption is used in the off-site dose calculations in Sections 5.2.1, 5.3.1 and 6 and Attachment II-7, II-9, II-11, II-13, II-15 and II-17.

3.8 A respirable fraction (RF) of 1.0 is used in this calculation. This fraction will be applied to the release of all the radionuclides from Pu waste in a DBE that may potentially cause a canister to breach. *Basis:* This assumption is conservatively based on worst case. *Usage:* This assumption is used in the off-site dose calculations in Section 6 and Attachment II-6, II-7, II-9, II-11, II-13, II-15 and II-17.

3.9 A leak path factor (LPF) of 1.0 is used in this calculation. *Basis:* Using a LPF of 1.0 implies taking no credit for source term reduction mechanisms such as gravitational settling or operation of the WHB ventilation system (i.e., HEPA filtration of the source term before it is released to the environment). This is a bounding assumption and hence, technically defensible. *Usage:* This assumption is used in the off-site dose calculations in Section 5.3.1 and Attachment II-7, II-11 and II-15.

3.10 A damage ratio (DR) of 1.0 is used in this calculation. *Basis:* Using a DR of 1.0 implies taking no credit for structural integrity provided by the can, tube, and canister the Pu is contained within. In addition, if the Pu can-in-canister canister is contained within a shipping cask or a disposal container, no credit is taken for the structural integrity of these systems as well. This is a bounding assumption and hence, technically defensible. *Usage:* This assumption is used in the off-site dose calculations in Section 5.3.1 and Attachment II-7, II-11 and II-15.

3.11 In calculating the fraction of inventory at risk, the only significant radioactive isotopes in the Pu canisters are listed in Table 5-1. *Basis:* This data is based on the *Report on Intact and Degraded Criticality for Selected Plutonium Waste Forms in a Geologic Repository, Volume II: Immobilized in Ceramic* (CRWMS M&O 1998, Table 2.2.3-4). *Usage:* This assumption is used in the off-site dose calculations in Section 5.2.1 and Attachment II-2.

3.12 In calculating the fraction of inventory at risk, it is assumed that all of the canisters containing Pu waste have radioisotopes with activities approximately equal to the values listed in Table 5-1. *Basis:* This data is based on the *Report on Intact and Degraded Criticality for Selected Plutonium Waste Forms in a Geologic Repository, Volume II: Immobilized in Ceramic* (CRWMS M&O 1998, Table 2.2.3-4). If the values in Table 5-1 may potentially not be bounding then an uncertainty analysis must be performed to determine the effect of activity on the doses relative to the dose limits. *Usage:* This assumption is used in the off-site dose calculations in Section 5.2.1 and Attachment II-2.

3.13 The inhalation dose per high level waste (HLW) canister for the HLW waste form is based on a maximum drop height of 448 inches. *Basis:* This data is based on the *High Level Vitrified Waste Dose Calculation* (CRWMS M&O 1999, Attachment VII-1). *Usage:* This assumption is used in the off-site dose calculations in Sections 5.1, 5.2.6 and 5.3.1 and Attachment II-2.

4. COMPUTER SOFTWARE AND MODEL USAGE

4.1 SCIENTIFIC AND ENGINEERING SOFTWARE

Not Applicable.

4.2 COMPUTATIONAL SUPPORT SOFTWARE

Excel 97 for Windows

All dose calculations performed to support this analysis were generated with Excel 97 spreadsheets, and run on Pentium personal computers. The Excel 97 platform was used to calculate doses for DBE scenarios analyzed (see Attachment II). The process, which was used to calculate doses, is described in Section 5.3. Dose results presented in this calculation were generated by the Excel spreadsheet and verified by visual inspection.

5. CALCULATIONS

5.1 CALCULATION DESCRIPTION

The purpose of this radiological analysis is to estimate the radioactive releases and resultant doses per canister to the public from a DBE that is assumed to occur within the WHB. In this calculation, doses received are by an off-site individual at 5-km from the radionuclide release point [Assumption 3.1]. Doses to individual organs and to the whole body are calculated, respectively, for exposure via inhalation and submersion.

The calculations, as described in the Methods Section (Section 2), are performed only for the plutonium can-in-canister waste form and are located in Attachment II. No calculations for the HLW are performed in this calculation, see *High Level Vitrified Waste Dose Calculation* (CRWMS M&O 1999) for details on the doses produced by this waste form [Assumption 3.13].

5.2 INPUT DATA

Design inputs are for preliminary design. These design inputs will require subsequent qualification before the analysis can be used to support procurement, fabrication, or construction activities.

5.2.1 Source Terms - Radionuclide Inventories

According to the *Report on Intact and Degraded Criticality for Selected Plutonium Waste Forms in a Geologic Repository, Volume II: Immobilized in Ceramic* (CRWMS M&O 1998, Table 2.2.3-4), the activity for radionuclides contained in a Pu can-in-canister canister, with the units curies per kilogram of plutonium plus americium (americium is included in this total due to the relatively rapid decay of ^{241}Pu to ^{241}Am) in the feed in the year 2010, are equal to values in Table 5-1 [Assumption 3.11]. This table lists the activity for the case where only 18-metric tons of plutonium, which contains impurities making it unsuitable for MOX reactor fuel, is disposed and the case where all 50-metric tons of surplus plutonium are disposed. Note that the plutonium containing the impurities (the 18-metric ton case) has the limiting activity per kilogram of plutonium plus americium in the feed (see Attachment II) [Assumption 3.12]. In addition, note that each of the radionuclides listed in Table 5-1 is considered to be released in particulate form rather than as a gas or a volatile. Thus, a single airborne release fraction (ARF) may be used to represent the release of these particulate due to a potential DBE [Assumption 3.7].

Table 5-1. Curies per kg of Total Plutonium plus Americium

Isotope	Activity (Ci per kg of Pu + Am)	
	18-Metric Ton Case	50-Metric Ton Case
^{238}Pu	4.2	2.1
^{239}Pu	56.3	57.7
^{240}Pu	19.2	15.0
^{241}Pu	165.0	99.3
^{241}Am	25.0	15.1
^{242}Pu	0.0034	0.00161

5.2.2 Plutonium Mass

The mass of the plutonium within the Pu can-in-canister canister is obtained from the *Report on Intact and Degraded Criticality for Selected Plutonium Waste Forms in a Geologic Repository, Volume II: Immobilized in Ceramic* (CRWMS M&O 1998, pp. 2 and 11). Table 5-2 presents the data for the plutonium waste form. Essentially in each Pu can-in-canister canister there are 7 tubes, 28 cans, and 560 disks of surplus Pu.

Table 5-2. Plutonium Waste Form Mass Data

Property	Value
Disks per can	20
Cans per tube	4
Tubes per Pu can-in-canister canister	7
Ceramic mass per can	8.755 kg
Maximum Pu per can-in-canister canister	28.68 kg
Maximum fraction of HLW displaced by Pu in a canister	0.12

5.2.3 Atmospheric Dispersion Factors (χ/Q)

The atmospheric dispersion factors are based on Yucca Mountain site-specific data obtained from the Environmental Field Program (Schalk, W. and Landwehr, D. 1998, Table 3). The values were calculated using the equations prescribed in Regulatory Guide 1.145. An atmospheric dispersion factor of 4.68×10^{-5} sec/m^3 [Assumption 3.4] is used in the dose calculations for the assumed 5-km dose receptor [Assumption 3.1].

5.2.4 Breathing Rate

An adult breathing rate of 3.33×10^{-4} m^3/s (20-litres/min) was assumed for all dose calculations [Assumption 3.3]. This is based on the Reference Man breathing rate established in ICRP 23 (ICRP 1974, p. 346) and accepted by the NRC for accident analysis (NRC 1997, p. 7-7). This breathing rate is based on the volume intake of air for "light activity" and is considered to be appropriate for DBE accident scenarios resulting in short-term ($\leq$ 8-hour) exposures to the public at the 5,000-meter site boundary [Assumption 3.1].

5.2.5 Inhalation and Submersion Dose Conversion Factors (DCFs)

Inhalation and air submersion DCFs are taken from Federal Guidance Report 11 and Federal Guidance Report 12, respectively (Eckerman et al. 1988 and Eckerman et al. 1993). A listing of the DCFs used in this analysis is given in Attachment II. DCFs generated by the EPA are generally accepted by the scientific and engineering community and found to be technically defensible.

The inhalation DCF of an isotope is dependent in part on its chemical form. This dependence is accounted for by the lung clearance class (D – daily, W – Weekly, Y – Yearly) used to evaluate the DCF of a given isotope. Some isotopes have only one lung clearance class, others have multiple lung clearance classes. For isotopes with multiple lung clearance classes, the lung clearance class that yields the highest DCF is assumed on a per organ basis [Assumption 3.6]. For example, Pu-238 (which has W- and Y-clearance classes) has the highest lung inhalation DCF for the Y-clearance class, while all of the other organs have the highest inhalation DCF for the W-clearance class.

5.2.6 HLW Doses Per HLW Canister for the HLW Waste Form

The HLW doses per HLW canister for the HLW waste form are obtained from the *High-Level Vitrified Waste Dose Calculation* for SRS HLW (CRWMS M&O 1999, Attachment VII-1). Table 5-3 presents the data for the inhalation and submersion dose for each organ [Assumption 3.13].

Table 5-3. HLW Doses per HLW Canister

Organ	Dose (rem)	
	Inhalation	Submersion
Gonad	1.57×10^{-1}	1.15×10^{-5}
Breast	1.52×10^{-3}	1.31×10^{-5}
Lung	2.11×10^{0}	1.14×10^{-5}
R Marrow	8.94×10^{-1}	1.11×10^{-5}
B Surface	$1.06 \times 10^{+1}$	1.89×10^{-5}
Thyroid	1.52×10^{-3}	1.18×10^{-5}
Remainder	3.92×10^{-1}	1.09×10^{-5}
Effective	6.42×10^{-1}	1.18×10^{-5}
Skin	N/A	5.14×10^{-5}
Lens of Eye	N/A	0.0

5.2.7 HEPA Filter Mitigation Factor

A single-stage HEPA filter has, by definition, an efficiency of no less than 99.97% (Burchsted et al. 1978, p. 9). Hence a mitigation factor of 3.0×10^{-4} can be applied to all particulate radionuclide releases that are drawn through the exhaust HEPA filters by the WHB heating, ventilation, and air-conditioning (HVAC) system.

5.3 CONSEQUENCE ANALYSIS

The purpose of this radiological analysis is to estimate the radioactive releases and resultant doses to the public from a bounding DBE that is assumed to occur within the WHB [see Assumption 3.2]. In this analysis, the doses received by an off-site individual at 5-km from the radionuclide release point are calculated. Doses to individual organs and to the whole body are calculated for exposure through inhalation and submersion.

First, an unmitigated analysis is performed and if it successfully demonstrates compliance with the regulatory requirements, using this approach could result in a simple licensing approach for DBEs with a minimum need for safety-related SSCs. A mitigated analysis is also performed to estimate the expected dose magnitude result from the DBE using credit for physical mechanisms that could mitigate the release in the event unmitigated consequences do not meet regulatory requirements.

The dose produced by both the Pu waste and the HLW contained in a Pu can-in-canister canister must be considered in this dose assessment for the bounding DBE. According to the *Report on Intact and Degraded Criticality for Selected Plutonium Waste Forms in a Geologic Repository, Volume II: Immobilized in Ceramic* (CRWMS M&O 1998, p. 11), the plutonium bearing canisters contain 88% of their maximum capacity for HLW glass (i.e., Pu makes up 12% of these canisters). Thus, considering HLW is homogeneously distributed through a HLW canister, the dose associated with the HLW in a canister containing Pu is the dose from a canister containing only HLW reduced by 12%. This is done for the dose associated with each organ prior to any additions to doses associated with the Pu.

5.3.1 Source Terms

This section presents the radionuclide source terms that are potentially available for release during a bounding DBE. The inhalation source terms are formed by the radionuclides available for release if the engineered barriers (i.e., the canisters) are breached. A person engulfed by the released radioactive plume, who inhales the radionuclides suspended in the plume, receives the inhalation dose. The inhalation doses are the 50-year committed dose equivalents. No crud is associated with these canisters since they are poured forms whose surfaces are neither corrosive nor exposed to a corrosive environment such as water.

Source terms are generated in units of curies so that they may be easily converted to units of dose. Each of the isotopes in the source terms is evaluated for its dose contribution to the gonad, breast, lung, red marrow, bone surface, thyroid, remainder, and whole body. Attachment II details these source term calculations for the Pu in the Pu can-in-canister canister. Details of the source term calculation for HLW can be found in the *High Level Vitrified Waste Dose Calculation* (CRWMS M&O 1999) [Assumption 3.13]. The HLW dose results from this calculation will be combined with the dose calculations for the Pu waste established in this analysis (as shown in Section 5.3.2) to determine the total potential dose produced by a breached canister containing Pu in cans and HLW.

The source term released to the environment by a postulated DBE for the Pu waste in a Pu can-in-canister canister is calculated by Equation (1) in Section 2:

$$ST_{j,Pu} = MAR_{j,Pu} \times DR_{j,Pu} \times ARF_{j,Pu} \times RF_{j,Pu} \times LPF_{j,Pu} \qquad (1)$$

Note that for Pu waste in a Pu can-in-canister canister, the damage ratio (DR), the leak path factor (LPF), and the airborne release fraction times the respirable fraction (ARF x RF) are constants. DR and LPF are assumed equal to one [Assumptions 3.10 and 3.9] for each isotope. ARF x RF is assumed equal to 1.6 x 10^{-3} for each isotope in this analysis [Assumption 3.7].

5.3.2 Inhalation and Submersion Dose Calculations

The inhalation dose to an individual from each isotope in the source term from the Pu waste per Pu can-in-canister canister is calculated by Equation (2) in Section 2:

$$D_{j,k,Pu}^{inh} = ST_{j,Pu} \times \frac{\chi}{Q} \times BR \times conv \times DCF_{j,k}^{inh} \tag{2}$$

while the air submersion dose is calculated by Equation (3):

$$D_{j,k,Pu}^{sub} = \frac{ST_{j,Pu}}{RF_{j,Pu}} \times \frac{\chi}{Q} \times conv \times DCF_{j,k}^{sub} \tag{3}$$

The total inhalation dose to an individual from each isotope in the source term in the Pu can-in-canister is calculated by Equation (4):

$$D_{j,k}^{inh} = D_{j,k,Pu}^{inh} + (1-x) D_{j,k,HLW}^{inh} \tag{4}$$

while the air submersion dose is calculated by Equation (5):

$$D_{j,k}^{sub} = D_{j,k,Pu}^{sub} + (1-x) D_{j,k,HLW}^{sub} \tag{5}$$

The radiation doses from the HLW are calculated in the *High Level Vitrified Waste Dose Calculation* (CRWMS M&O 1999). The maximum fraction of the Pu can-in-canister canister that is Pu waste is found in Table 5-2. Note that the radiation dose from the Pu waste in the above equations is on a per canister basis, which assumes some maximum fraction of a canister contains Pu waste. The values calculated for HLW are based on a canister filled entirely with HLW.

5.3.3 CDE, DDE, CEDE, and TEDE Calculations

In this section, the equations used to produce dose equivalents in terms of the radiation doses calculated in the Section 5.3.2 and Attachment II are shown.

The TEDE and the CDE + DDE dose measures, ignoring the ingestion dose pathway [Assumption 3.5], are expressed as Equations (6) and (7):

$$TEDE = CEDE + DDE = \sum_j D_{j,effective}^{inh} + \sum_j D_{j,effective}^{sub} \tag{6}$$

$$CDE_k + DDE = \sum_j D_{j,k}^{inh} + \sum_j D_{j,effective}^{sub} \quad \text{where } k \neq \text{effective or skin} \tag{7}$$

The skin and extremities dose is equal to calculated using Equation (8):

$$SKIN = \sum_j D_{j,skin}^{sub} \tag{8}$$

5.4 DBE DOSE CONSEQUENCES

Equations (1) through (8) are used to establish the dose consequences per canister. In the unmitigated calculation, the canisters, shipping casks, and disposal containers are assumed to provide no mitigation for potential releases. In addition, no credit is taken for any hindrance the WHB and other structures may provide against the leakage of the released radionuclides to the site boundary. This includes not taking credit for any HEPA filters that may be present in these facilities.

6. RESULTS

The offsite dose consequence results from the calculations in Attachment II for the bounding 18-metric ton case are summarized in Table 6-1. Table 6-1 summarizes the unmitigated doses and the mitigated dose consequences, which were produced assuming the presence of HEPA filters with an efficiency of 3.0×10^{-4}. No other credit has been taken for other potential mitigation features (e.g., the shipping cask).

It should be noted that the maximum fraction of Pu waste in the Pu can-in-canister canister is an input to this analysis as opposed to the maximum fraction of HLW in this canister due to the significant impact the smaller quantity of Pu waste has on the doses. This input essentially limits the amount of Pu allowed in these canisters. Table 6-1 summarizes the sensitivity of the results to the amount of plutonium in these can-in-canister canisters. In addition, Figure 6-1 illustrates how the TEDE and the maximum organ dose (CDE+DDE) vary with the fraction of Pu waste in a canister. The values in this figure were obtained by varying the fraction of HLW displaced by Pu in a canister, which modifies the dose contribution of the HLW. In addition, the Pu dose contribution was corrected with the ratio of the HLW displacement fraction to 0.12 (the current displacement fraction). This latter correction is made to correct for the addition or reduction of Pu mass with the change in the displacement fraction (e.g., a displacement fraction of 0.1 reduces the amount Pu mass by 0.1/0.12 = 0.833 or 16.7%). Attachment V contains the calculations relevant to this Figure. Note, however, that the reference displacement fraction in this analysis is considered equal to 0.12.

Another important factor in these dose calculations is the ARF. In this calculation, the ARF is equal to a constant [Assumption 3.7]. However, if the ARF fraction did vary for the Pu waste, say with a postulated drop height, then Figure 6-2 illustrates how the Pu and total canister TEDE and maximum organ dose (i.e., bone surface, CDE+DDE) vary with this fraction. The doses in this figure were calculated by simply multiplying the plutonium portion of the doses (for the 0.12 unmitigated case in Table 6-1) by the ratio of the selected ARF divided by the 1.6×10^{-3} and adding the HLW doses. The HLW doses are not modified in this calculation by the ARF. Attachment V contains the calculations relevant to this Figure.

Other inputs that may significantly impact the dose results (e.g., increase doses) in this calculation include: (1) the assumed location of the restricted area boundary (i.e., 5,000-m [Assumption 3.1]), (2) the χ/Q value that was obtained from an unconfirmed MGR calculation [Assumption 3.4], (3) the breathing rate that was obtained from an unconfirmed source [Assumption 3.3], and (4) the activity of the radionuclides in the Pu waste [Assumption 3.12].

Table 6-1. Mitigated and Unmitigated Dose Consequences for a Breached Pu Can-In-Canister Canister

Fraction of HLW Displaced by Pu	Number of Canisters	Dose (rem)			
		TEDE	Highest CDE + DDE	Skin	Lens of the Eye
0.10 (Unmitigated)	1 Pu	28.3 (27.7-rem due to Pu only)	513.3 (bone surface)	4.6×10^{-5}	0.0
0.10 (Mitigated)	1 Pu	0.0085 (0.0083-rem due to Pu only)	0.15 (bone surface)	1.4×10^{-8}	0.0
0.12 (Unmitigated)	1 Pu	33.8 (33.3-rem due to Pu only)	613.9 (bone surface)	4.6×10^{-5}	0.0
0.12 (Mitigated)	1 Pu	0.010 (9.98-mrem due to Pu only)	0.18 (bone surface)	1.4×10^{-8}	0.0
0.20 (Unmitigated)	1 Pu	56.0 (55.4 rem due to Pu only)	1016.0 (bone surface)	4.2×10^{-5}	0.0
0.20 (Mitigated)	1 Pu	0.017 (0.0166 rem due to Pu only)	0.305 (bone surface)	1.3×10^{-8}	0.0

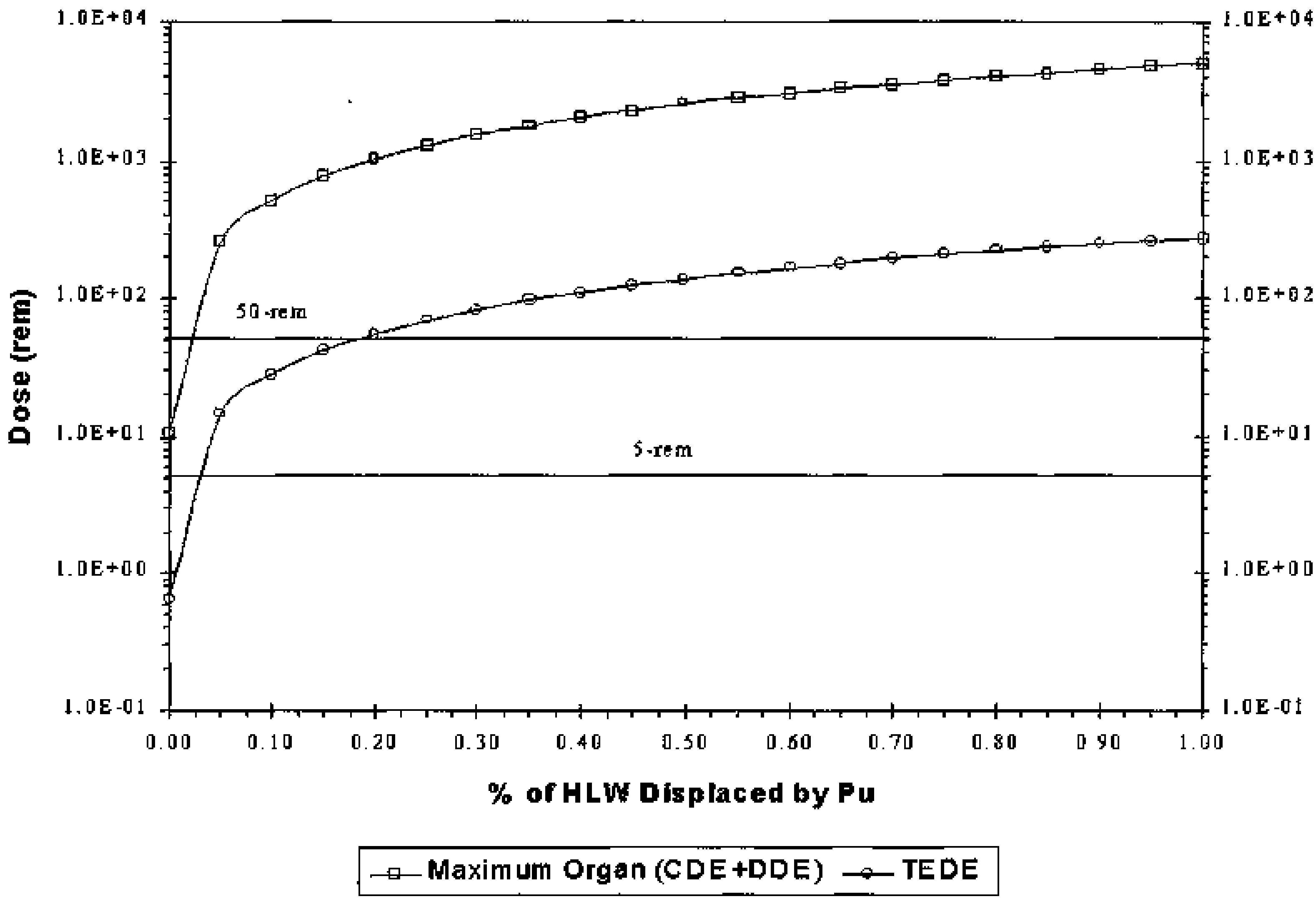

Figure 6-1. Change in Dose as a Function of the Fraction of Plutonium Waste in a Canister

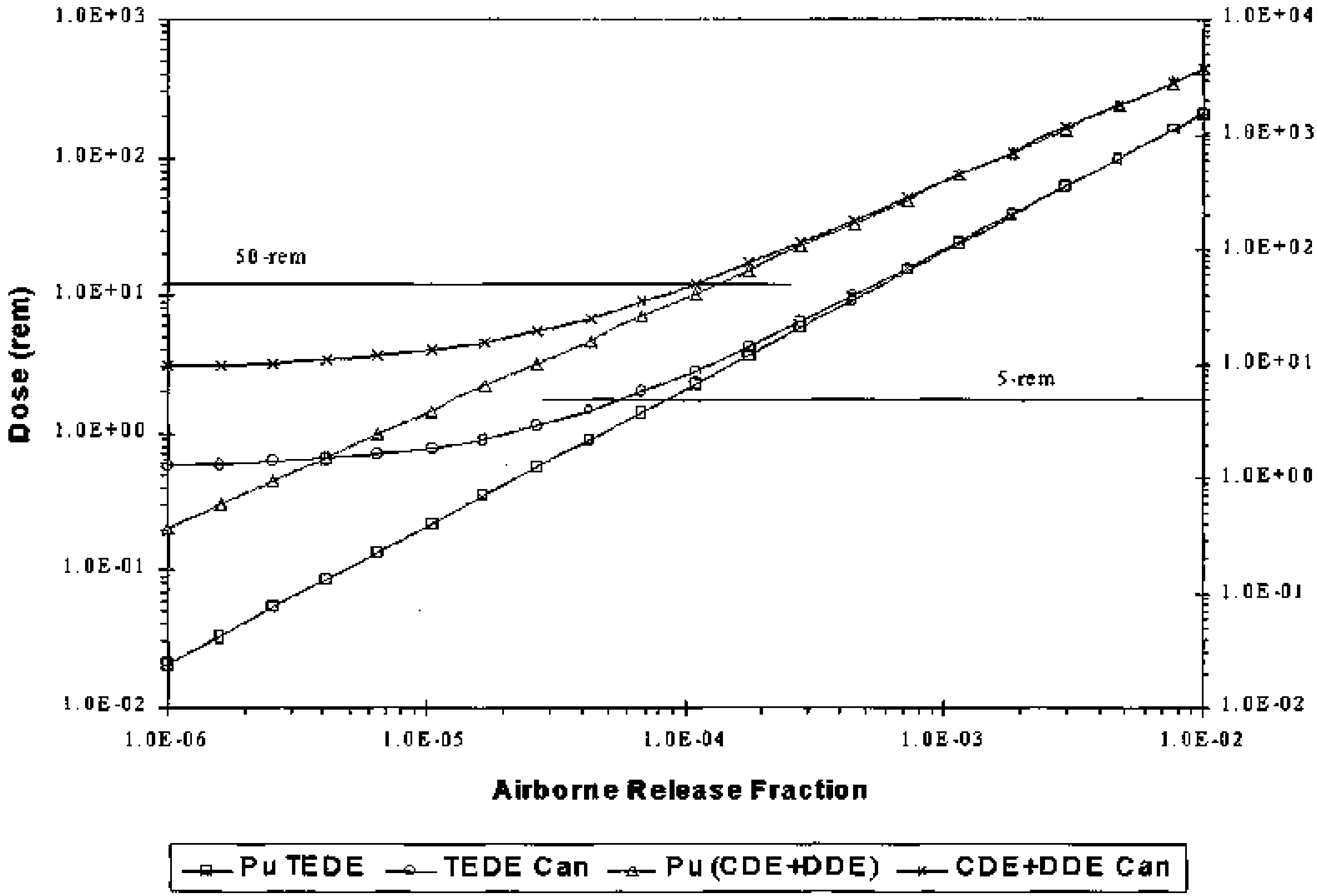

Figure 6-2. Effect of the ARF x RF Factor on the Dose from a Plutonium/HLW Canister

7. ATTACHMENTS

Attachment I	Acronyms
Attachment II	Dose Consequence Analysis for Pu Can-in-Canister Canisters
Attachment III	Pu Can-In-Canister Sketch
Attachment IV	Document Input Reference Sheets
Attachment V	Calculations for Figures 6-1 and 6-2

Attachment I

Acronyms

ANL	Argonne National Laboratory
ARF	Airborne Release Fraction
BR	Breathing Rate
CDA	Controlled Design Assumptions
CDE	Committed Dose Equivalent
CEDE	Committed Effective Dose Equivalent
DBE	Design Basis Event
DCF	Dose Conversion Factor
DDE	Deep Dose Equivalent
DR	Damage Ratio
EPA	Environmental Protection Agency
HEPA	High-Efficiency Particulate Air
HLW	High-Level Waste
HVAC	Heating, Ventilation and Air-Conditioning
ICRP	International Commission on Radiological Protection
ISFSI	Independent Spent Fuel Storage Installation
LPF	Leak Path Factor
M&O	Management and Operating Contractor
MAR	Material-at-Risk
MGR	Monitored Geologic Repository
NRC	Nuclear Regulatory Commission
QA	Quality Assurance
RF	Respirable Fraction
SSC	Structure, System, and Component
ST	Source Term
TBD	To Be Determined
TBV	To Be Verified
TEDE	Total Effective Dose Equivalent
WHB	Waste Handling Building

Attachment II

Dose Consequence Analysis for Pu Can-in-Canister Canisters

The following pages contain a listing of the Excel 97 spreadsheets used to calculate the dose for the Pu can-in-canister canister, which includes the HLW in this canister. The following is a listing of the spreadsheets involved (note that the equations in the text are not implemented in the same exact form in the spreadsheets):

- **Pu MAR** - lists the material-at-risk in the Pu can-in-canister (Table 5-1) [No calculations].
- **DCF** - dose conversion factors (see Section 5.2.5) [No calculations].
- **Pu Source Term (18 MT)** - calculation of source terms for a Pu can-in-canister for the 18-MT case. The calculations performed in this sheet involve multiplying the material at risk (MAR) by the dose conversion factors (DCFs) and the conversion factors for sieverts to rem and curies to bequerels for each radio-isotope and each organ. These source terms are then added together for each organ.
- **Pu Source Term (50 MT)** - calculation of source terms for a Pu can-in-canister for the 50-MT case. The calculations performed in this sheet involve multiplying the material at risk (MAR) by the dose conversion factors (DCFs) and the conversion factors for sieverts to rem and curies to bequerels for each radio-isotope and each organ. These source terms are then added together for each organ.
- **HLW Inputs** - organ doses as calculated in *High Level Vitrified Waste Dose Calculation* (CRWMS M&O, 1999b) [No calculations].
- **Pu Canister Dose no HEPAs (0.1)** - calculation of unmitigated doses for a Pu/HLW canister with 10% of the HLW displaced by Pu waste. The Pu waste form doses are calculated in this sheet by multiplying the source terms for each organ, as calculated in the Pu Source Term (18 MT) sheet, by the ARF, RF (if applicable), Mitigation Factor, Breathing Rate, and X/Q value. These doses are then added to the doses from the HLW waste form which have been reduced by the fraction of HLW displaced by the Pu waste form. The following sheets all perform the same calculations with different mitigation factors and fractions of displaced HLW.
- **Pu Canister Dose W HEPAs (0.1)** - calculation of mitigated doses for a Pu/HLW canister with 10% of the HLW displaced by Pu waste
- **Pu Canister Dose no HEPAs (0.12)** - calculation of unmitigated doses for a Pu/HLW canister with 12% of the HLW displaced by Pu waste
- **Pu Canister Dose W HEPAs (0.12)** - calculation of mitigated doses for a Pu/HLW canister with 12% of the HLW displaced by Pu waste
- **Pu Canister Dose no HEPAs (0.2)** - calculation of unmitigated doses for a Pu/HLW canister with 20% of the HLW displaced by Pu waste
- **Pu Canister Dose W HEPAs (0.2)** - calculation of mitigated doses for a Pu/HLW canister with 20% of the HLW displaced by Pu waste

MATERIAL AT RISK		
Isotope	Activity (Ci per kg of Pu + Am)	
	50-Metric Ton Case	18-Metric Ton Case
^{238}Pu	2.1	4.2
^{239}Pu	57.7	56.3
^{240}Pu	15	19.2
^{241}Pu	99.3	165
^{241}Am	15.1	25
^{242}Pu	0.00161	0.0034

Exposure-to-Dose Conversion Factors for Inhalation								
	Committed Dose Equivalent per Unit Intake (Sv/Bq)							
Isotope	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainde	Effective
^{238}Pu	2.80E-05	1.00E-09	3.20E-04	1.52E-04	1.90E-03	9.62E-10	7.02E-05	1.06E-04
^{239}Pu	3.18E-05	9.22E-10	3.23E-04	1.69E-04	2.11E-03	9.03E-10	7.56E-05	1.16E-04
^{240}Pu	3.18E-05	9.51E-10	3.23E-04	1.69E-04	2.11E-03	9.05E-10	7.56E-05	1.16E-04
^{241}Pu	6.82E-07	3.06E-11	3.18E-06	3.36E-06	4.20E-05	1.24E-11	1.31E-06	2.23E-06
^{241}Am	3.25E-05	2.67E-09	1.84E-05	1.74E-04	2.17E-03	1.06E-09	7.82E-05	1.20E-04
^{242}Pu	3.02E-05	9.45E-10	3.07E-06	1.61E-04	2.01E-03	8.79E-10	7.18E-05	1.11E-04

Exposure-to-Dose Conversion Factors for Submersion										
	Committed Dose Equivalent per Unit Intake (Sv/s per Bq/m^3)									
Isotope	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainde	Effective	Skin	Lens of Eye
^{238}Pu	6.56E-18	1.27E-17	1.06E-18	1.68E-18	9.30E-18	4.01E-18	1.99E-18	4.88E-18	4.09E-17	0.00E+00
^{239}Pu	4.84E-18	7.55E-18	2.65E-18	2.67E-18	9.47E-18	3.88E-18	2.86E-18	4.24E-18	1.86E-17	0.00E+00
^{240}Pu	6.36E-18	1.23E-17	1.09E-18	1.65E-18	9.26E-18	3.92E-18	1.96E-18	4.75E-18	3.92E-17	0.00E+00
^{241}Pu	7.19E-20	8.67E-20	6.48E-20	5.63E-20	2.19E-19	6.98E-20	6.09E-20	7.25E-20	1.17E-19	0.00E+00
^{241}Am	8.58E-16	1.07E-15	6.74E-16	5.21E-16	2.87E-15	7.83E-16	6.34E-16	8.18E-16	1.28E-15	0.00E+00
^{242}Pu	5.34E-18	1.03E-17	9.69E-19	1.43E-18	7.90E-18	3.32E-18	1.68E-18	4.01E-18	3.27E-17	0.00E+00

Plutonium Inhalation Source Term - 18 Metric Ton Case (28.68-kg Pu)								
	Rem/Canister							
Isotope	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective
^{238}Pu	1.25E+10	4.46E+05	1.43E+11	6.77E+10	8.47E+11	4.29E+05	3.13E+10	4.72E+10
^{239}Pu	1.90E+11	5.51E+06	1.93E+12	1.01E+12	1.26E+13	5.39E+06	4.52E+11	6.93E+11
^{240}Pu	6.48E+10	1.94E+06	6.58E+11	3.44E+11	4.30E+12	1.84E+06	1.54E+11	2.36E+11
^{241}Pu	1.19E+10	5.36E+05	5.57E+10	5.88E+10	7.35E+11	2.17E+05	2.29E+10	3.90E+10
^{241}Am	8.62E+10	7.08E+06	4.88E+10	4.62E+11	5.76E+12	2.81E+06	2.07E+11	3.18E+11
^{242}Pu	1.09E+07	3.41E+02	1.11E+06	5.81E+07	7.25E+08	3.17E+02	2.59E+07	4.00E+07
Total	**3.65E+11**	**1.55E+07**	**2.83E+12**	**1.94E+12**	**2.42E+13**	**1.07E+07**	**8.67E+11**	**1.33E+12**

Plutonium Submersion Source Term - 18 Metric Ton Case (28.68-kg Pu)										
	(Rem-m^3)/(s-Canister)									
Isotope	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective	Skin	Lens Eye
^{238}Pu	2.92E-03	5.66E-03	4.72E-04	7.49E-04	4.14E-03	1.79E-03	8.87E-04	2.17E-03	1.82E-02	0.00E+00
^{239}Pu	2.89E-02	4.51E-02	1.58E-02	1.60E-02	5.66E-02	2.32E-02	1.71E-02	2.53E-02	1.11E-01	0.00E+00
^{240}Pu	1.30E-02	2.51E-02	2.22E-03	3.36E-03	1.89E-02	7.99E-03	3.99E-03	9.68E-03	7.99E-02	0.00E+00
^{241}Pu	1.26E-03	1.52E-03	1.13E-03	9.86E-04	3.83E-03	1.22E-03	1.07E-03	1.27E-03	2.05E-03	0.00E+00
^{241}Am	2.28E+00	2.84E+00	1.79E+00	1.38E+00	7.61E+00	2.08E+00	1.68E+00	2.17E+00	3.40E+00	0.00E+00
^{242}Pu	1.93E-06	3.72E-06	3.50E-07	5.16E-07	2.85E-06	1.20E-06	6.06E-07	1.45E-06	1.18E-05	0.00E+00
Total	**2.32E+00**	**2.92E+00**	**1.81E+00**	**1.40E+00**	**7.70E+00**	**2.11E+00**	**1.70E+00**	**2.21E+00**	**3.61E+00**	**0.00E+00**

NOTES

[A] Inhalation Source Term = [MAR (Ci/kg)] [28.68 kg/canister] [DCF(Sv/Bq)] [3.7×10^{10} Bq/Ci] [100 Rem/Sv]

[B] Submersion Source Term = [MAR (Ci/kg)] [28.68 kg/canister] [DCF(Sv-m^3/Bq-s)] [3.7×10^{10} Bq/Ci] [100 Rem/Sv]

[C] Maximum Plutonium per canister = 28.68 kg at 12% HLW volume displacement.

Plutonium Inhalation Source Term - 50 Metric Ton Case (28.68-kg Pu)								
	Rem/Canister							
Isotope	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective
^{238}Pu	6.24E+09	2.23E+05	7.13E+10	3.39E+10	4.23E+11	2.14E+05	1.56E+10	2.36E+10
^{239}Pu	1.95E+11	5.65E+06	1.98E+12	1.03E+12	1.29E+13	5.53E+06	4.63E+11	7.10E+11
^{240}Pu	5.06E+10	1.51E+06	5.14E+11	2.69E+11	3.36E+12	1.44E+06	1.20E+11	1.85E+11
^{241}Pu	7.19E+09	3.22E+05	3.35E+10	3.54E+10	4.43E+11	1.31E+05	1.38E+10	2.35E+10
^{241}Am	5.21E+10	4.28E+06	2.95E+10	2.79E+11	3.48E+12	1.70E+06	1.25E+11	1.92E+11
^{242}Pu	5.16E+06	1.61E+02	5.24E+05	2.75E+07	3.43E+08	1.50E+02	1.23E+07	1.90E+07
Total	**3.11E+11**	**1.20E+07**	**2.63E+12**	**1.65E+12**	**2.06E+13**	**9.01E+06**	**7.38E+11**	**1.13E+12**

Plutonium Submersion Source Term - 50 Metric Ton Case (28.68-kg Pu)										
	(Rem-m^3)/(s-Canister)									
Isotope	Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective	Skin	Lens Eye
^{238}Pu	1.46E-03	2.83E-03	2.36E-04	3.74E-04	2.07E-03	8.94E-04	4.43E-04	1.09E-03	9.11E-03	0.00E+00
^{239}Pu	2.96E-02	4.62E-02	1.62E-02	1.63E-02	5.80E-02	2.38E-02	1.75E-02	2.60E-02	1.14E-01	0.00E+00
^{240}Pu	1.01E-02	1.96E-02	1.73E-03	2.63E-03	1.47E-02	6.24E-03	3.12E-03	7.56E-03	6.24E-02	0.00E+00
^{241}Pu	7.58E-04	9.14E-04	6.83E-04	5.93E-04	2.31E-03	7.36E-04	6.42E-04	7.64E-04	1.23E-03	0.00E+00
^{241}Am	1.37E+00	1.71E+00	1.08E+00	8.35E-01	4.60E+00	1.25E+00	1.02E+00	1.31E+00	2.05E+00	0.00E+00
^{242}Pu	9.12E-07	1.76E-06	1.66E-07	2.44E-07	1.35E-06	5.67E-07	2.87E-07	6.85E-07	5.59E-06	0.00E+00
Total	**1.42E+00**	**1.78E+00**	**1.10E+00**	**8.55E-01**	**4.68E+00**	**1.29E+00**	**1.04E+00**	**1.35E+00**	**2.24E+00**	**0.00E+00**

NOTES

[A] Inhalation Source Term = [MAR (Ci/kg)] [28.68 kg/canister] [DCF(Sv/Bq)] [3.7 x 10^{10} Bq/Ci] [100 Rem/Sv]

[B] Submersion Source Term = [MAR (Ci/kg)] [28.68 kg/canister] [DCF(Sv-m^3/Bq-s)] [3.7 x 10^{10} Bq/Ci] [100 Rem/Sv]

[C] Maximum Plutonium per canister = 28.68 kg at 12% HLW volume displacement.

HLW Doses per HLW Canister		
Organ	Inhalation Dose (rem)	Submersion Dose (rem)
(1)	(11)	(12)
Gonad	1.57E-01	1.15E-05
Breast	1.52E-03	1.31E-05
Lung	2.11E+00	1.14E-05
R Marrow	8.94E-01	1.11E-05
B Surface	1.06E+01	1.89E-05
Thyroid	1.52E-03	1.18E-05
Remainder	3.92E-01	1.09E-05
Effective	6.42E-01	1.18E-05
Skin	NA	5.14E-05
Lens of Eye	NA	0.00E+00

Breathing Rate:	3.33E-04	**(13)**
X/Q:	4.68E-05	**(14)**
Mitigation Factor:	1	**(15)**

Off-Site Inhalation Dose without HEPA Filters (10% HLW Displaced by Pu)									
	Pu-Dose	# of canisters	ARF x RF	Mitigation Factor	Breathing Rate	5000 meter X/Q	Dose due to Pu-waste	Dose due to HLW	Offsite 5000-m Can Dose
Organ	(rem/can)	(-)	(-)	(-)	(m^3/sec)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Gonad	3.65E+11	1	1.60E-03	1	3.33E-04	4.68E-05	7.59E+00	1.41E-01	7.73E+00
Breast	1.55E+07	1	1.60E-03	1	3.33E-04	4.68E-05	3.22E-04	1.37E-03	1.69E-03
Lung	2.83E+12	1	1.60E-03	1	3.33E-04	4.68E-05	5.89E+01	1.90E+00	6.08E+01
R Marrow	1.94E+12	1	1.60E-03	1	3.33E-04	4.68E-05	4.04E+01	8.05E-01	4.12E+01
B Surface	2.42E+13	1	1.60E-03	1	3.33E-04	4.68E-05	5.04E+02	9.54E+00	**5.13E+02**
Thyroid	1.07E+07	1	1.60E-03	1	3.33E-04	4.68E-05	2.22E-04	1.37E-03	1.59E-03
Remainder	8.67E+11	1	1.60E-03	1	3.33E-04	4.68E-05	1.80E+01	3.53E-01	1.84E+01
Effective	1.33E+12	1	1.60E-03	1	3.33E-04	4.68E-05	2.77E+01	5.78E-01	**2.83E+01**

Off-Site Submersion Dose without HEPA Filters (10% HLW Displaced by Pu)								
	Pu-Dose	# of canisters	ARF	Mitigation Factor	5000 meter X/Q	Dose due to Pu-waste	Dose due to HLW	Offsite 5000-m Can Dose
Organ	(rem-m^3/s-can)	(-)	(-)	(-)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(7)	(8)	(9)	(10)
Gonad	2.32E+00	1	1.60E-03	1	4.68E-05	1.45E-07	1.04E-05	1.05E-05
Breast	2.92E+00	1	1.60E-03	1	4.68E-05	1.82E-07	1.18E-05	1.20E-05
Lung	1.81E+00	1	1.60E-03	1	4.68E-05	1.13E-07	1.03E-05	1.04E-05
R Marrow	1.40E+00	1	1.60E-03	1	4.68E-05	8.76E-08	1.00E-05	1.01E-05
B Surface	7.70E+00	1	1.60E-03	1	4.68E-05	4.80E-07	1.71E-05	**1.75E-05**
Thyroid	2.11E+00	1	1.60E-03	1	4.68E-05	1.32E-07	1.06E-05	1.07E-05
Remainder	1.70E+00	1	1.60E-03	1	4.68E-05	1.06E-07	9.84E-06	9.95E-06
Effective	2.21E+00	1	1.60E-03	1	4.68E-05	1.38E-07	1.06E-05	**1.07E-05**
Skin	3.61E+00	1	1.60E-03	1	4.68E-05	2.25E-07	4.63E-05	**4.65E-05**
Lens of Eye	0.00E+00	1	1.60E-03	1	4.68E-05	0.00E+00	0.00E+00	**0.00E+00**

Continuation from Previous Page

Fraction of HLW Displaced by Pu [1, p. 11] = 0.1

no HEPAs	5000-m
Dose	(rem)
CEDE	28.298
DDE (eff.)	0.000
TEDE	28.298
CDE (max)	513.322
CDE + DDE	513.322
Lens of Eye	0.000
Skin	4.649E-05

<u>Inhalation</u>

(8) = (2) x (3) x (4) x (5) x (6) x (7) x 0.1/0.12

(9) = (1 - 0.1) x (3) x [HLW (11)] x (5)/[HLW (15)] x (6)/[HLW (13)] x (7)/[HLW (14)]

(10) = (8) + (9)

<u>Submersion</u>

(8) = (2) x (3) x (4) x (5) x (6) x (7) x 0.1/0.12

(9) = (1 - 0.1) x (3) x [HLW (11)] x (5)/[HLW (15)] x (7)/[HLW (14)]

(10) = (8) + (9)

Off-Site Inhalation Dose with HEPA Filters (10% HLW Displaced by Pu)									
Organ	Pu-Dose	# of canisters	ARF x RF	Mitigation Factor	Breathing Rate	5000 meter X/Q	Dose due to Pu-waste	Dose due to HLW	Offsite 5000-m Can Dose
	(rem/can)	(-)	(-)	(-)	(m^3/sec)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Gonad	3.65E+11	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	2.28E-03	4.24E-05	2.32E-03
Breast	1.55E+07	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	9.67E-08	4.10E-07	5.07E-07
Lung	2.83E+12	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	1.77E-02	5.70E-04	1.82E-02
R Marrow	1.94E+12	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	1.21E-02	2.41E-04	1.23E-02
B Surface	2.42E+13	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	1.51E-01	2.86E-03	1.54E-01
Thyroid	1.07E+07	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	6.67E-08	4.10E-07	4.77E-07
Remainder	8.67E+11	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	5.41E-03	1.06E-04	5.51E-03
Effective	1.33E+12	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	8.32E-03	1.73E-04	8.49E-03

Off-Site Submersion Dose with HEPA Filters (10% HLW Displaced by Pu)								
Organ	Pu-Dose	# of canisters	ARF	Mitigation Factor	5000 meter X/Q	Dose due to Pu-waste	Dose due to HLW	Offsite 5000-m Can Dose
	(rem-m^3/s-can)	(-)	(-)	(-)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(7)	(8)	(9)	(10)
Gonad	2.32E+00	1	1.60E-03	3.00E-04	4.68E-05	4.35E-11	3.11E-09	3.15E-09
Breast	2.92E+00	1	1.60E-03	3.00E-04	4.68E-05	5.46E-11	3.55E-09	3.60E-09
Lung	1.81E+00	1	1.60E-03	3.00E-04	4.68E-05	3.38E-11	3.08E-09	3.12E-09
R Marrow	1.40E+00	1	1.60E-03	3.00E-04	4.68E-05	2.63E-11	3.01E-09	3.03E-09
B Surface	7.70E+00	1	1.60E-03	3.00E-04	4.68E-05	1.44E-10	5.12E-09	5.26E-09
Thyroid	2.11E+00	1	1.60E-03	3.00E-04	4.68E-05	3.95E-11	3.17E-09	3.21E-09
Remainder	1.70E+00	1	1.60E-03	3.00E-04	4.68E-05	3.19E-11	2.95E-09	2.99E-09
Effective	2.21E+00	1	1.60E-03	3.00E-04	4.68E-05	4.13E-11	3.17E-09	3.22E-09
Skin	3.61E+00	1	1.60E-03	3.00E-04	4.68E-05	6.75E-11	1.39E-08	1.39E-08
Lens of Eye	0.00E+00	1	1.60E-03	3.00E-04	4.68E-05	0.00E+00	0.00E+00	0.00E+00

Continuation from Previous Page

Fraction of HLW Displaced by Pu [1, p. 11] = 0.1

<u>Inhalation</u>

(8) = (2) x (3) x (4) x (5) x (6) x (7) x 0.1/0.12

(9) = (1 - 0.1) x (3) x [HLW (11)] x (5)/[HLW (15)] x (6)/[HLW (13)] x (7)/[HLW (14)]

(10) = (8) + (9)

<u>Submersion</u>

(8) = (2) x (3) x (4) x (5) x (6) x (7) x 0.1/0.12

(9) = (1 - 0.1) x (3) x [HLW (11)] x (5)/[HLW (15)] x (7)/[HLW (14)]

(10) = (8) + (9)

HEPAs	5000-m
Dose	(rem)
CEDE	0.008
DDE (eff.)	0.000
TEDE	0.008
CDE (max)	0.154
CDE + DDE	0.154
Lens of Eye	0.000
Skin	0.000

Off-Site Inhalation Dose without HEPA Filters (12% HLW Displaced by Pu)									
Organ	Pu-Dose	# of canisters	ARF x RF	Mitigation Factor	Breathing Rate	5000 meter X/Q	Dose due to Pu-waste	Dose due to HLW	Offsite 5000-m Can Dose
	(rem/can)	(-)	(-)	(-)	(m^3/sec)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Gonad	3.65E+11	1	1.60E-03	1	3.33E-04	4.68E-05	9.11E+00	1.38E-01	9.25E+00
Breast	1.55E+07	1	1.60E-03	1	3.33E-04	4.68E-05	3.87E-04	1.34E-03	1.72E-03
Lung	2.83E+12	1	1.60E-03	1	3.33E-04	4.68E-05	7.07E+01	1.86E+00	7.25E+01
R Marrow	1.94E+12	1	1.60E-03	1	3.33E-04	4.68E-05	4.84E+01	7.87E-01	4.92E+01
B Surface	2.42E+13	1	1.60E-03	1	3.33E-04	4.68E-05	6.05E+02	9.33E+00	**6.14E+02**
Thyroid	1.07E+07	1	1.60E-03	1	3.33E-04	4.68E-05	2.67E-04	1.34E-03	1.60E-03
Remainder	8.67E+11	1	1.60E-03	1	3.33E-04	4.68E-05	2.16E+01	3.45E-01	2.20E+01
Effective	1.33E+12	1	1.60E-03	1	3.33E-04	4.68E-05	3.33E+01	5.65E-01	**3.38E+01**

Off-Site Submersion Dose without HEPA Filters (12% HLW Displaced by Pu)								
Organ	Pu-Dose	# of canisters	ARF	Mitigation Factor	5000 meter X/Q	Dose due to Pu-waste	Dose due to HLW	Offsite 5000-m Can Dose
	(rem-m^3/s-can)	(-)	(-)	(-)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(7)	(8)	(9)	(10)
Gonad	2.32E+00	1	1.60E-03	1	4.68E-05	1.74E-07	1.01E-05	1.03E-05
Breast	2.92E+00	1	1.60E-03	1	4.68E-05	2.18E-07	1.16E-05	1.18E-05
Lung	1.81E+00	1	1.60E-03	1	4.68E-05	1.35E-07	1.01E-05	1.02E-05
R Marrow	1.40E+00	1	1.60E-03	1	4.68E-05	1.05E-07	9.80E-06	9.91E-06
B Surface	7.70E+00	1	1.60E-03	1	4.68E-05	5.76E-07	1.67E-05	**1.72E-05**
Thyroid	2.11E+00	1	1.60E-03	1	4.68E-05	1.58E-07	1.03E-05	1.05E-05
Remainder	1.70E+00	1	1.60E-03	1	4.68E-05	1.28E-07	9.63E-06	9.75E-06
Effective	2.21E+00	1	1.60E-03	1	4.68E-05	1.65E-07	1.03E-05	**1.05E-05**
Skin	3.61E+00	1	1.60E-03	1	4.68E-05	2.70E-07	4.52E-05	**4.55E-05**
Lens of Eye	0.00E+00	1	1.60E-03	1	4.68E-05	0.00E+00	0.00E+00	**0.00E+00**

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Fraction of HLW Displaced by Pu [1, p. 11] = 0.12

no HEPAs	5000-m
Dose	(rem)
CEDE	33.829
DDE (eff.)	0.000
TEDE	33.829
CDE (max)	613.866
CDE + DDE	613.866
Lens of Eye	0.000
Skin	4.550E-05

Inhalation

(8) = (2) x (3) x (4) x (5) x (6) x (7) x 0.12/0.12

(9) = (1 - 0.12) x (3) x [HLW (11)] x (5)/[HLW (15)] x (6)/[HLW (13)] x (7)/[HLW (14)]

(10) = (8) + (9)

Submersion

(8) = (2) x (3) x (4) x (5) x (6) x (7) x 0.12/0.12

(9) = (1 - 0.12) x (3) x [HLW (11)] x (5)/[HLW (15)] x (7)/[HLW (14)]

(10) = (8) + (9)

Off-Site Inhalation Dose with HEPA Filters (12% HLW Displaced by Pu)									
Organ	Pu-Dose (rem/can)	# of canisters (-)	ARF x RF (-)	Mitigation Factor (-)	Breathing Rate (m^3/sec)	5000 meter X/Q (sec/m^3)	Dose due to Pu-waste (rem)	Dose due to HLW (rem)	Offsite 5000-m Can Dose (rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Gonad	3.65E+11	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	2.73E-03	4.14E-05	2.78E-03
Breast	1.55E+07	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	1.16E-07	4.01E-07	5.17E-07
Lung	2.83E+12	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	2.12E-02	5.57E-04	2.18E-02
R Marrow	1.94E+12	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	1.45E-02	2.36E-04	1.48E-02
B Surface	2.42E+13	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	1.81E-01	2.80E-03	**1.84E-01**
Thyroid	1.07E+07	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	8.00E-08	4.01E-07	4.81E-07
Remainder	8.67E+11	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	6.49E-03	1.03E-04	6.59E-03
Effective	1.33E+12	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	9.98E-03	1.69E-04	**1.01E-02**

Off-Site Submersion Dose with HEPA Filters (12% HLW Displaced by Pu)								
Organ	Pu-Dose (rem-m^3/s-can)	# of canisters (-)	ARF (-)	Mitigation Factor (-)	5000 meter X/Q (sec/m^3)	Dose due to Pu-waste (rem)	Dose due to HLW (rem)	Offsite 5000-m Can Dose (rem)
(1)	(2)	(3)	(4)	(5)	(7)	(8)	(9)	(10)
Gonad	2.32E+00	1	1.60E-03	3.00E-04	4.68E-05	5.22E-11	3.04E-09	3.09E-09
Breast	2.92E+00	1	1.60E-03	3.00E-04	4.68E-05	6.55E-11	3.47E-09	3.54E-09
Lung	1.81E+00	1	1.60E-03	3.00E-04	4.68E-05	4.06E-11	3.02E-09	3.06E-09
R Marrow	1.40E+00	1	1.60E-03	3.00E-04	4.68E-05	3.15E-11	2.94E-09	2.97E-09
B Surface	7.70E+00	1	1.60E-03	3.00E-04	4.68E-05	1.73E-10	5.00E-09	**5.17E-09**
Thyroid	2.11E+00	1	1.60E-03	3.00E-04	4.68E-05	4.74E-11	3.10E-09	3.15E-09
Remainder	1.70E+00	1	1.60E-03	3.00E-04	4.68E-05	3.83E-11	2.89E-09	2.93E-09
Effective	2.21E+00	1	1.60E-03	3.00E-04	4.68E-05	4.96E-11	3.10E-09	**3.15E-09**
Skin	3.61E+00	1	1.60E-03	3.00E-04	4.68E-05	8.10E-11	1.36E-08	**1.37E-08**
Lens of Eye	0.00E+00	1	1.60E-03	3.00E-04	4.68E-05	0.00E+00	0.00E+00	**0.00E+00**

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Fraction of HLW Displaced by Pu [1, p. 11] = 0.12

Inhalation

(8) = (2) x (3) x (4) x (5) x (6) x (7) x 0.12/0.12

(9) = (1 - 0.12) x (3) x [HLW (11)] x (5)/[HLW (15)] x (6)/[HLW (13)] x (7)/[HLW (14)]

(10) = (8) + (9)

Submersion

(8) = (2) x (3) x (4) x (5) x (6) x (7) x 0.12/0.12

(9) = (1 - 0.12) x (3) x [HLW (11)] x (5)/[HLW (15)] x (7)/[HLW (14)]

(10) = (8) + (9)

HEPAs	5000-m
Dose	(rem)
CEDE	0.010
DDE (eff.)	0.000
TEDE	0.010
CDE (max)	0.184
CDE + DDE	0.184
Lens of Eye	0.000
Skin	0.000

Off-Site Inhalation Dose without HEPA Filters (20% HLW Displaced by Pu)									
Organ	Pu-Dose (rem/can)	# of canisters (-)	ARF x RF (-)	Mitigation Factor (-)	Breathing Rate (m^3/sec)	5000 meter X/Q (sec/m^3)	Dose due to Pu-waste (rem)	Dose due to HLW (rem)	Offsite 5000-m Can Dose (rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Gonad	3.65E+11	1	1.60E-03	1	3.33E-04	4.68E-05	1.52E+01	1.26E-01	1.53E+01
Breast	1.55E+07	1	1.60E-03	1	3.33E-04	4.68E-05	6.45E-04	1.22E-03	1.86E-03
Lung	2.83E+12	1	1.60E-03	1	3.33E-04	4.68E-05	1.18E+02	1.69E+00	1.20E+02
R Marrow	1.94E+12	1	1.60E-03	1	3.33E-04	4.68E-05	8.07E+01	7.15E-01	8.14E+01
B Surface	2.42E+13	1	1.60E-03	1	3.33E-04	4.68E-05	1.01E+03	8.48E+00	1.02E+03
Thyroid	1.07E+07	1	1.60E-03	1	3.33E-04	4.68E-05	4.45E-04	1.22E-03	1.66E-03
Remainder	8.67E+11	1	1.60E-03	1	3.33E-04	4.68E-05	3.60E+01	3.14E-01	3.64E+01
Effective	1.33E+12	1	1.60E-03	1	3.33E-04	4.68E-05	5.54E+01	5.14E-01	5.60E+01

Off-Site Submersion Dose without HEPA Filters (20% HLW Displaced by Pu)								
Organ	Pu-Dose (rem-m^3/s-can)	# of canisters (-)	ARF (-)	Mitigation Factor (-)	5000 meter X/Q (sec/m^3)	Dose due to Pu-waste (rem)	Dose due to HLW (rem)	Offsite 5000-m Can Dose (rem)
(1)	(2)	(3)	(4)	(5)	(7)	(8)	(9)	(10)
Gonad	2.32E+00	1	1.60E-03	1	4.68E-05	2.90E-07	9.21E-06	9.50E-06
Breast	2.92E+00	1	1.60E-03	1	4.68E-05	3.64E-07	1.05E-05	1.09E-05
Lung	1.81E+00	1	1.60E-03	1	4.68E-05	2.26E-07	9.14E-06	9.37E-06
R Marrow	1.40E+00	1	1.60E-03	1	4.68E-05	1.75E-07	8.91E-06	9.08E-06
B Surface	7.70E+00	1	1.60E-03	1	4.68E-05	9.61E-07	1.52E-05	1.61E-05
Thyroid	2.11E+00	1	1.60E-03	1	4.68E-05	2.64E-07	9.40E-06	9.67E-06
Remainder	1.70E+00	1	1.60E-03	1	4.68E-05	2.13E-07	8.75E-06	8.96E-06
Effective	2.21E+00	1	1.60E-03	1	4.68E-05	2.76E-07	9.40E-06	9.68E-06
Skin	3.61E+00	1	1.60E-03	1	4.68E-05	4.50E-07	4.11E-05	4.16E-05
Lens of Eye	0.00E+00	1	1.60E-03	1	4.68E-05	0.00E+00	0.00E+00	0.00E+00

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Fraction of HLW Displaced by Pu [1, p. 11] = 0.2

no HEPAs	5000-m
Dose	(rem)
CEDE	55.954
DDE (eff.)	0.000
TEDE	55.954
CDE (max)	1016.043
CDE + DDE	1016.043
Lens of Eye	0.000
Skin	4.157E-05

Inhalation

(8) = (2) x (3) x (4) x (5) x (6) x (7) x 0.2/0.12

(9) = (1 - 0.2) x (3) x [HLW (11)] x (5)/[HLW (15)] x (6)/[HLW (13)] x (7)/[HLW (14)]

(10) = (8) + (9)

Submersion

(8) = (2) x (3) x (4) x (5) x (6) x (7) x 0.2/0.12

(9) = (1 - 0.2) x (3) x [HLW (11)] x (5)/[HLW (15)] x (7)/[HLW (14)]

(10) = (8) + (9)

Off-Site Inhalation Dose with HEPA Filters (20% HLW Displaced by Pu)									
Organ	Pu-Dose	# of canisters	ARF x RF	Mitigation Factor	Breathing Rate	5000 meter X/Q	Dose due to Pu-waste	Dose due to HLW	Offsite 5000-m Can Dose
	(rem/can)	(-)	(-)	(-)	(m^3/sec)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Gonad	3.65E+11	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	4.56E-03	3.77E-05	4.59E-03
Breast	1.55E+07	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	1.93E-07	3.65E-07	5.58E-07
Lung	2.83E+12	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	3.53E-02	5.06E-04	3.59E-02
R Marrow	1.94E+12	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	2.42E-02	2.15E-04	2.44E-02
B Surface	2.42E+13	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	3.02E-01	2.54E-03	**3.05E-01**
Thyroid	1.07E+07	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	1.33E-07	3.65E-07	4.98E-07
Remainder	8.67E+11	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	1.08E-02	9.41E-05	1.09E-02
Effective	1.33E+12	1	1.60E-03	3.00E-04	3.33E-04	4.68E-05	1.66E-02	1.54E-04	**1.68E-02**

Off-Site Submersion Dose with HEPA Filters (20% HLW Displaced by Pu)								
Organ	Pu-Dose	# of canisters	ARF	Mitigation Factor	5000 meter X/Q	Dose due to Pu-waste	Dose due to HLW	Offsite 5000-m Can Dose
	(rem-m^3/s-can)	(-)	(-)	(-)	(sec/m^3)	(rem)	(rem)	(rem)
(1)	(2)	(3)	(4)	(5)	(7)	(8)	(9)	(10)
Gonad	2.32E+00	1	1.60E-03	3.00E-04	4.68E-05	8.69E-11	2.76E-09	2.85E-09
Breast	2.92E+00	1	1.60E-03	3.00E-04	4.68E-05	1.09E-10	3.15E-09	3.26E-09
Lung	1.81E+00	1	1.60E-03	3.00E-04	4.68E-05	6.77E-11	2.74E-09	2.81E-09
R Marrow	1.40E+00	1	1.60E-03	3.00E-04	4.68E-05	5.25E-11	2.67E-09	2.73E-09
B Surface	7.70E+00	1	1.60E-03	3.00E-04	4.68E-05	2.88E-10	4.55E-09	**4.84E-09**
Thyroid	2.11E+00	1	1.60E-03	3.00E-04	4.68E-05	7.91E-11	2.82E-09	2.90E-09
Remainder	1.70E+00	1	1.60E-03	3.00E-04	4.68E-05	6.38E-11	2.63E-09	2.69E-09
Effective	2.21E+00	1	1.60E-03	3.00E-04	4.68E-05	8.27E-11	2.82E-09	**2.90E-09**
Skin	3.61E+00	1	1.60E-03	3.00E-04	4.68E-05	1.35E-10	1.23E-08	**1.25E-08**
Lens of Eye	0.00E+00	1	1.60E-03	3.00E-04	4.68E-05	0.00E+00	0.00E+00	**0.00E+00**

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Fraction of HLW Displaced by Pu [1, p. 11] = 0.2

Inhalation

(8) = (2) x (3) x (4) x (5) x (6) x (7) x 0.2/0.12

(9) = (1 - 0.2) x (3) x [HLW (11)] x (5)/[HLW (15)] x (6)/[HLW (13)] x (7)/[HLW (14)]

(10) = (8) + (9)

Submersion

(8) = (2) x (3) x (4) x (5) x (6) x (7) x 0.2/0.12

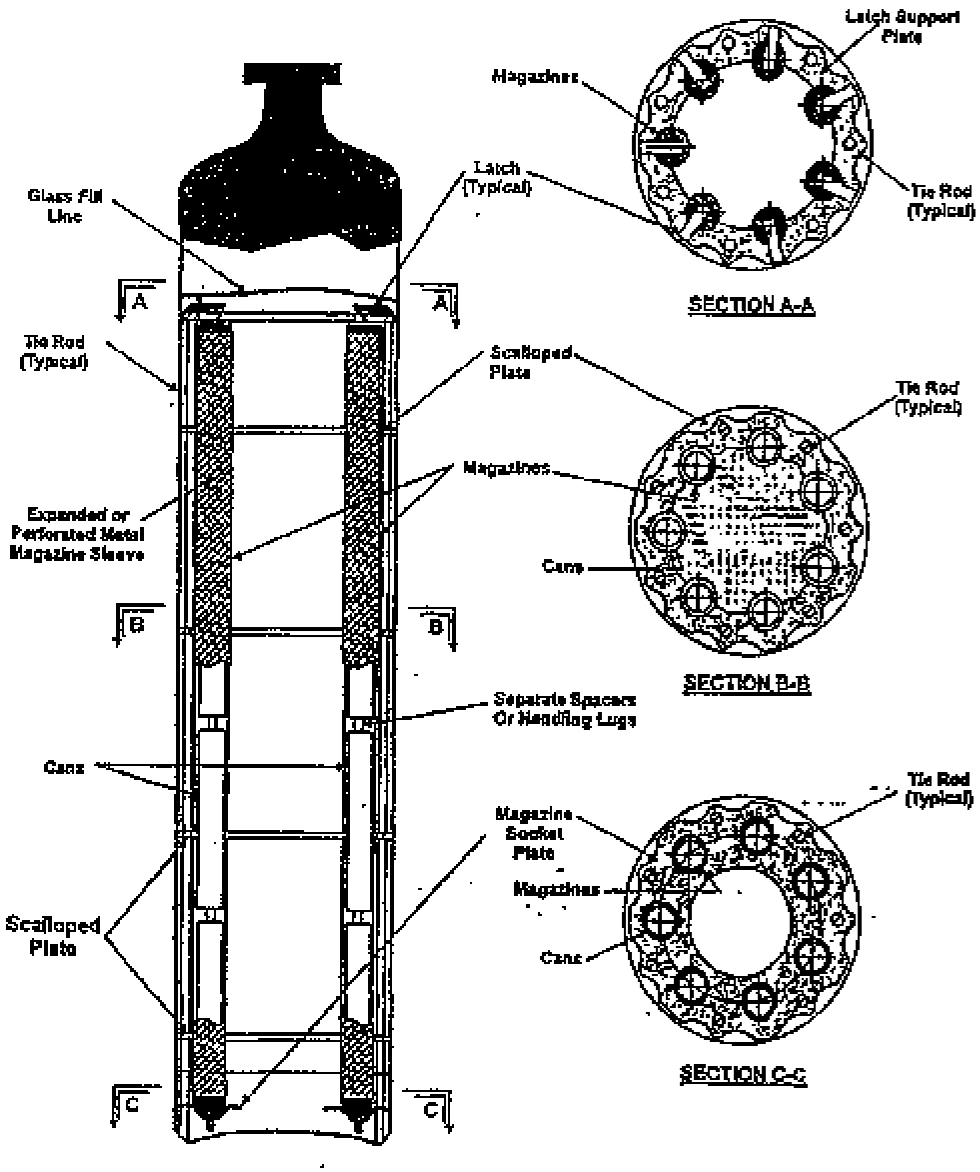
(9) = (1 - 0.2) x (3) x [HLW (11)] x (5)/[HLW (15)] x (7)/[HLW (14)]

(10) = (8) + (9)

HEPAs	5000-m
Dose	(rem)
CEDE	0.017
DDE (eff.)	0.000
TEDE	0.017
CDE (max)	0.305
CDE + DDE	0.305
Lens of Eye	0.000
Skin	0.000

Attachment III

Pu Can-In-Canister Sketch



Can-In-Canister sketch from SRS showing cross section with 4 cans in a tube and 7 tubes in a DWPF canister (CRWMS M&O 1998, Figure 2.2-1)

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DOCUMENT INPUT REFERENCE SHEET

1. Document Identifier No./Rev.: CAL-WPS-SE-000001 REV00	Change:	Title: Plutonium/High Level Vitrified Waste - DBE Offsite Dose Calculation

Input Document							8. TBV Due To		
2a	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmer
1	AP-3.12Q, Rev. 00. *Calculations*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19990702.0312	All	N/A	Entire	General reference.	N/A	N/A	N/A	N/A
2	QAP-2-0, Rev. 05. *Conduct of Activities*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19980826.0209	All	N/A	1.0	General reference.	N/A	N/A	N/A	N/A
3	DOE 1998. *Quality Assurance Requirements and Description for the Civilian Radioactive Waste Management Program (QARD)*. DOE/RW/0333P Rev. 08. Washington D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: MOL.19980601.0022	All	N/A	1.0	General reference.	N/A	N/A	N/A	N/A
4	QAP-2-3, Rev. 10. *Classification of Permanent Items*. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990316.0006.	All	N/A	1.0	General reference.	N/A	N/A	N/A	N/A
5	DOE 1994. *DOE Handbook: Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities. Volume I - Analysis of Experimental Data*. DOE-HDBK-3010-94. Washington, DC: U.S. Department of Energy. TIC: 233366. Initial Use.	p. 1-2	TBV-3233	2.1	General equation for source term calculation.	2	N/A	X	N/A

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2a	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmer
6	Regulatory Guide 1.109. 1977. *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I.* Washington, DC: U.S. Nuclear Regulatory Commission. TIC: 222641.	C.2 and C.3	TBV-3104	2.2	Derivation of dose equations are based on this Regulatory Guide	2	N/A	X	N/A
7	Eckerman, K.F.; Wolbarst, A.B.; and Richardson, A.C.B. 1988. *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion.* Federal Guidance Report No. 11, EPA-520/1-88-020. Washington, DC: Office if Radiation Programs, U.S. Environmental Protection Agency. TIC: 203350	Table 2.1 pp. 121-153, and 182	TBV-3100	2.2, 5.2.5	Dose Conversion Factors for Inhalation	2	N/A	X	N/A
8	CRWMS M&O 1999. *DOE High-Level Vitrified Waste Dose Calculation.* CAL-WPS-SE-000002, Rev. 00. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19990720.0403.	Att. VII	N/A	2.2, 5.1, 5.2.6, 5.3.1, 5.3.2, Table 5-3, Att. II, 3.13	Inhalation and submersion doses per HLW canister. Inhalation and submersion doses per HLW canister based on 448-inch maximum drop height.	N/A	N/A	N/A	N/A
9	YMP (Yucca Mountain Site Characterization Office) 1999. *Monitored Geologic Repository Requirements Document.* YMP/CM-0025, Rev. 3, DCN 01. Las Vegas, Nevada: Yucca Mountain Site Characterization Office. ACC: MOL.19990429.0228.	3.3.J	TBV-3098	3.1	Site boundary will be 5,000 m from WHB ventilation release point and 5,000 m from emplacement area ventilation exhaust shaft.	2	X	N/A	N/A

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Input Document							8. TBV Due To		
2a	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmer
10	Regulatory Guide 1.25. 1972. *Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors.* Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 238372.	C.i	TBV-3103	3.2	Release of radionuclides occurs over a 2-hour period.	2	N/A	X	N/A
11	ICRP (International Commission on Radiological Protection) 1974. *Report of the Task Group on Reference Man.* International Commission on Radiological Protection Publication No. 23, Oxford, England: Pergamon Press. TIC: 237218.	p. 346	TBV-3102	3.3, 5.2.4	20 l/min breathing rate for the volume intake of air for "light activity"	2	N/A	X	N/A
12	Schalk, Walt and Landwehr, Doug 1998. *Preliminary X/Q Concentration Estimates Using NRC Regulatory Guide 1.145 as Implemented by the XQ145 Software Routine.* Walt Schalk and Doug Landwehr (CRWMS M&O). LV.EAP.WWS. 12/98-004. December 16, 1998. ACC: MOL.19990222.0117.	Table 3	TBV-3082	3.4, 5.2.3	Atmospheric dispersion factor (X/Q) of 4.68E-5 at a 5,000-m distance from radioactive release for 0.50 percent exceeded.	2	X	X	N/A
13	NRC 1982. *Regulatory Guide 1.145, Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants.* Rev. 1 Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 222460. Initial Use.	All	TBV-3236	3.4, 5.2.3	Method used to calculate the atmospheric dispersion factor (X/Q) of 4.68E-5 at a 5,000 m distance from radioactive release for 0.50 percent exceeded.	2	N/A	X	N/A

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Input Document							8. TBV Due To		
2a	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section	4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	Unqual.	From Uncontrolled Source	Un-confirmed
14	CRWMS M&O 1998. *Report on Intact and Degraded Criticality for Selected Plutonium Waste Forms in a Geologic Repository, Volume II: Immobilized in Ceramic.* BBA000000-01717-5705-00020, Rev. 01. Las Vegas, Nevada: CRWMS M&O. ACC: MOL.19981217.0112. Initial Use.	Table 2.2.3-4	TBV-3268	3.11, 5.2.1, Table 5-1	Only significant radionuclides in Pu canisters.	2	N/A	X	N/A
		Table 2.2.3-4		3.12, 5.2.1, Table 5-1	Activities of radionuclides in Pu canisters.	2	N/A	X	N/A
		pp. 2, 11		5.2.2, Table 5-2, 5.3	Pu mass and Pu waste form data.	2	N/A	X	N/A
		Figure 2.2-1		Att. III	Can-in-Canister sketch	2	N/A	X	N/A
15	NRC 1997. *Standard Review Plan for Dry Cask Storage Systems: Final Report.* NUREG-1536. Washington, D.C.: U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards: Spent Fuel Project Office. TIC: 232373.	p. 7-7	N/A	5.2.4	General reference to adult breathing rate of 3.33E-4 m^3/sec as acceptable.	N/A	N/A	N/A	N/A
16	Eckerman, K.F. and Ryman, J.C. 1993. *External Exposure to Radionuclides in Air, Water, and Soil.* Federal Guidance Report No. 12, EPA–402-R-93-081. Oak Ridge, Tennessee: Oak Ridge National Laboratory; Washington, D.C.: Environmental Protection Agency, Office of Radiation and Indoor Air. TIC: 225472.	Table III.1 pp. 57-73	TBV-3101	5.2.5	Dose Conversion Factors for Air Submersion.	2	N/A	X	N/A

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Input Document			4. Input Status	5. Section Used in	6. Input Description	7. TBV/TBD Priority	8. TBV Due To		
2a	2. Technical Product Input Source Title and Identifier(s) with Version	3. Section					Unqual.	From Uncontrolled Source	Un-confirmer
17	Burchsted, C.A.; Fuller, A.B.; and Kahn, J.E. 1978. *Nuclear Air Cleaning Handbook, Design, Construction, and Testing of High-Efficiency Air Cleaning Systems for Nuclear Application.* ERDA 76-21. Oak Ridge National Laboratory. TIC: NNA.19901127.0194. Initial Use	p. 9	TBV-3269	5.2.7	HEPA filter mitigation factor of 3.0e-4	2	N/A	X	N/A
18	Assumption. Initial Use.	N/A	TBV-3270	3.7, 5.2.1, 5.3.1, 6	It is assumed that the airborne release fraction (ARF) for Pu in a can-in-canister canister is equal to 1.6E-3.	2	X	N/A	N/A
19	ANL (Argonne National Laobratory) 1982. Final Report of Experimental Laboratory-Scale Brittle Fracture Studies of Glasses and Ceramics. ANL-82-39. Argonne National Laboratory: Argonne, Illinois. TIC: 225736. Initial Use	Table 6, p. 24	TBV-3315	3.7, 5.2.1, 5.3.1, 6	Data that support the assumption that the ARF for release fraction (ARF) for Pu in a can-in-canister canister is equal to 1.6E-3.	2	X	N/A	N/A

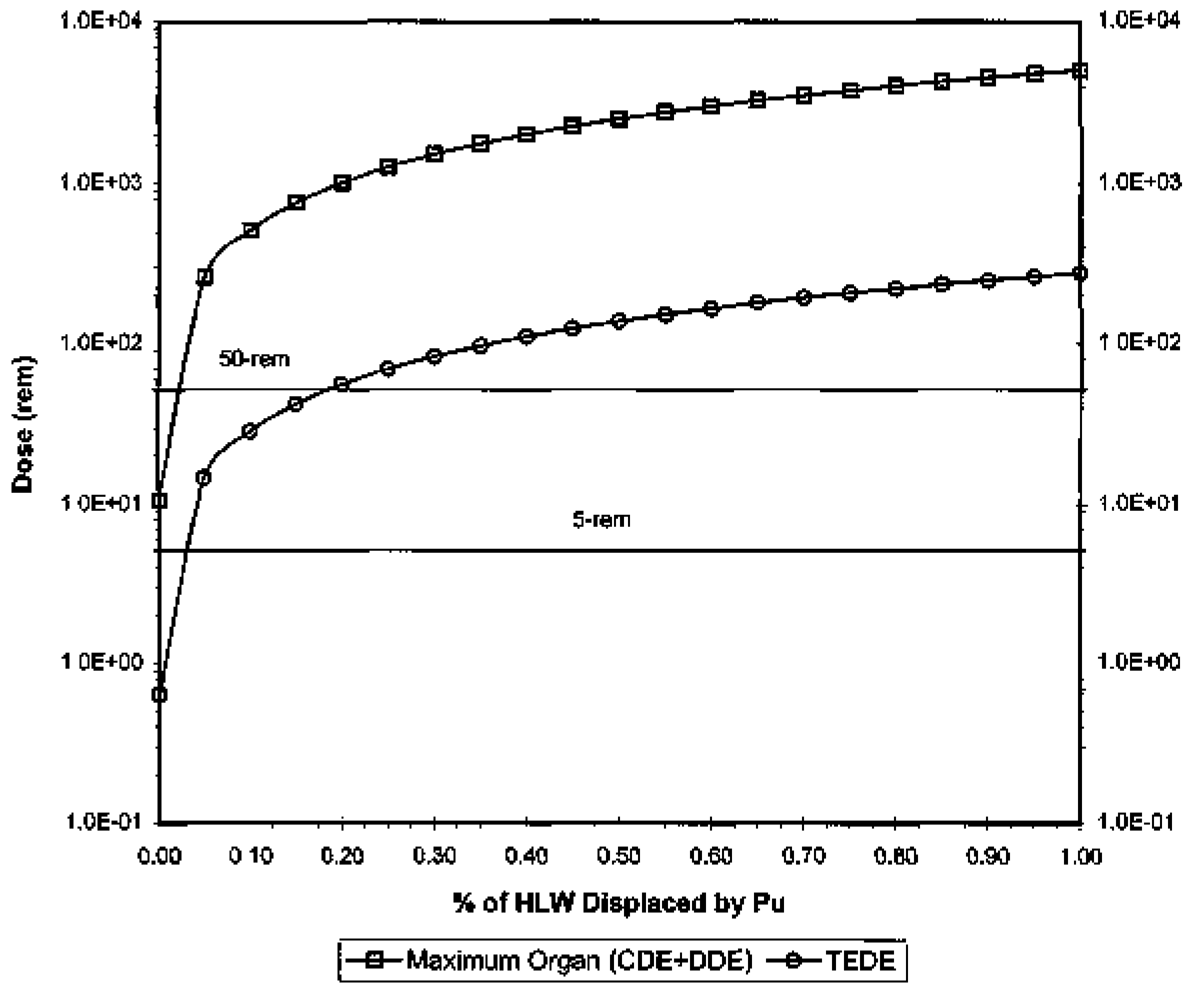
Attachment V

Calculations for Figures 6-1 and 6-2

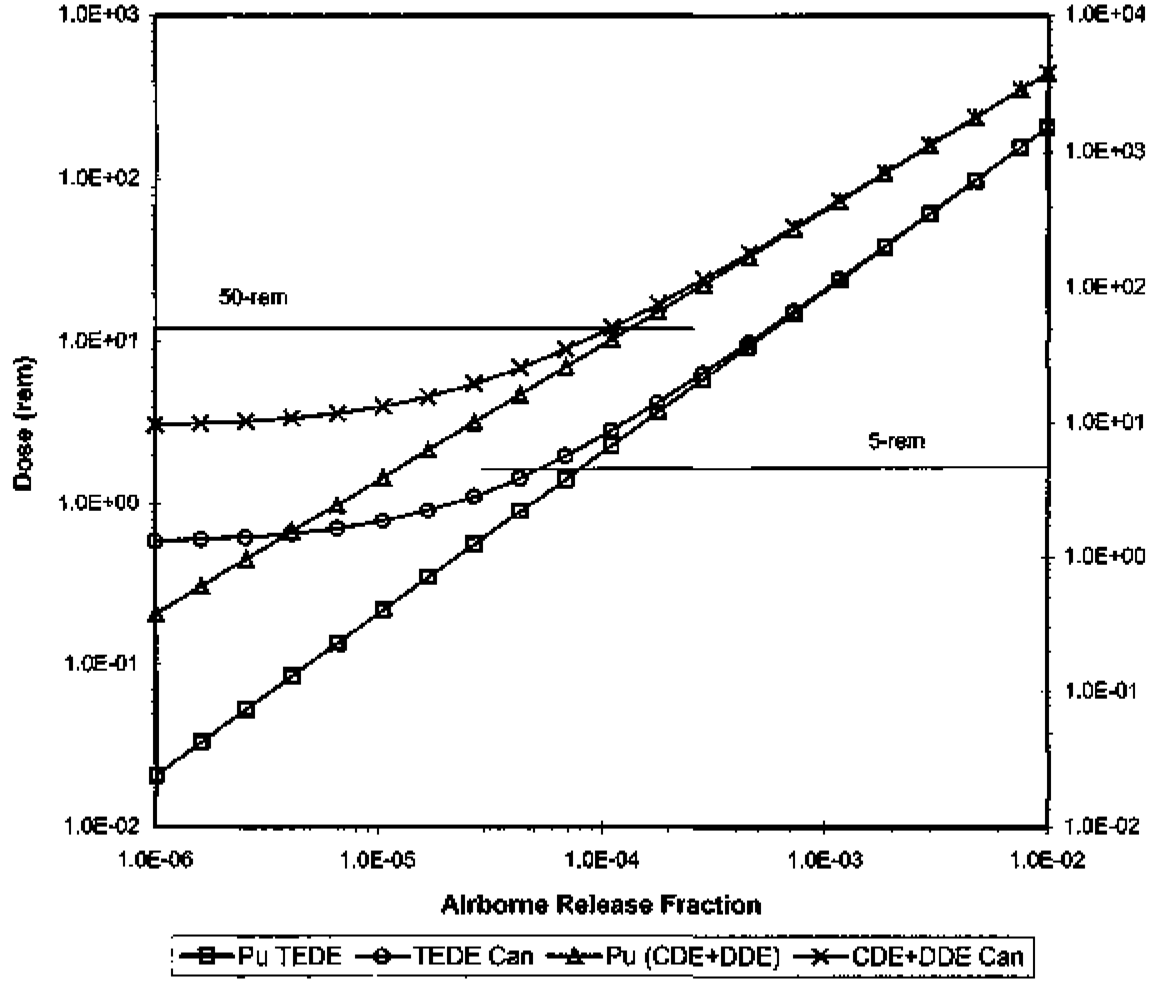
The following pages contain a listing of the Excel 97 spreadsheets used to calculate the data used in Figures 6-1 and 6-2 in the text. The following is a listing of the spreadsheets involved:

- **Figure 6.1** - calculations to plot Figure 6-1. This Figure illustrates the effect of changing the fraction of HLW displaced by Pu.
- **Figure 6.2** - calculations to plot Figure 6-2. This Figure illustrates the effect of changing the ARF on canister doses.

x	ratio x/0.12	Dose (rem)					
		Pu TEDE	HLW TEDE	TEDE	Pu (CDE+DDE)	HLW (CDE+DDE)	CDE + DDE
0.000	0.000	0.000	0.642	0.642	0.000	10.600	10.600
0.050	0.417	13.860	0.610	14.470	251.891	10.070	261.961
0.100	0.833	27.720	0.578	28.298	503.782	9.540	513.322
0.150	1.250	41.580	0.546	42.126	755.673	9.010	764.683
0.200	1.667	55.441	0.514	55.954	1007.563	8.480	1016.043
0.250	2.083	69.301	0.482	69.782	1259.454	7.950	1267.404
0.300	2.500	83.161	0.449	83.610	1511.345	7.420	1518.765
0.350	2.917	97.021	0.417	97.438	1763.236	6.890	1770.126
0.400	3.333	110.881	0.385	111.266	2015.127	6.360	2021.487
0.450	3.750	124.741	0.353	125.094	2267.018	5.830	2272.848
0.500	4.167	138.601	0.321	138.922	2518.908	5.300	2524.208
0.550	4.583	152.462	0.289	152.751	2770.799	4.770	2775.569
0.600	5.000	166.322	0.257	166.579	3022.690	4.240	3026.930
0.650	5.417	180.182	0.225	180.407	3274.581	3.710	3278.291
0.700	5.833	194.042	0.193	194.235	3526.472	3.180	3529.652
0.750	6.250	207.902	0.161	208.063	3778.363	2.650	3781.013
0.800	6.667	221.762	0.128	221.891	4030.253	2.120	4032.373
0.850	7.083	235.623	0.096	235.719	4282.144	1.590	4283.734
0.900	7.500	249.483	0.064	249.547	4534.035	1.060	4535.095
0.950	7.917	263.343	0.032	263.375	4785.926	0.530	4786.456
1.000	8.333	277.203	0.000	277.203	5037.817	0.000	5037.817


1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01
Dose (rem)
50-rem
5-rem
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
% of HLW Displaced by Pu
Maximum Organ (CDE+DDE)
TEDE

ARF	ratio ARF/0.0016	Dose (rem) Pu TEDE	HLW TEDE	TEDE	Pu (CDE+DDE)	HLW (CDE+DDE)	CDE + DDE
1.00E-06	6.25E-04	0.021	0.565	0.586	0.378	9.328	9.706
1.60E-06	1.00E-03	0.033	0.565	0.598	0.605	9.328	9.933
2.56E-06	1.60E-03	0.053	0.565	0.618	0.967	9.328	10.295
4.10E-06	2.56E-03	0.085	0.565	0.650	1.548	9.328	10.876
6.55E-06	4.10E-03	0.136	0.565	0.701	2.476	9.328	11.804
1.05E-05	6.55E-03	0.218	0.565	0.783	3.962	9.328	13.290
1.68E-05	1.05E-02	0.349	0.565	0.914	6.339	9.328	15.667
2.68E-05	1.68E-02	0.558	0.565	1.123	10.142	9.328	19.470
4.29E-05	2.68E-02	0.893	0.565	1.458	16.228	9.328	25.556
6.87E-05	4.29E-02	1.429	0.565	1.994	25.965	9.328	35.293
1.10E-04	6.87E-02	2.286	0.565	2.851	41.544	9.328	50.872
1.76E-04	1.10E-01	3.657	0.565	4.222	66.470	9.328	75.798
2.81E-04	1.76E-01	5.852	0.565	6.417	106.351	9.328	115.679
4.50E-04	2.81E-01	9.363	0.565	9.928	170.162	9.328	179.490
7.21E-04	4.50E-01	14.981	0.565	15.546	272.260	9.328	281.588
1.15E-03	7.21E-01	23.969	0.565	24.534	435.616	9.328	444.944
1.84E-03	1.15E+00	38.351	0.565	38.916	696.985	9.328	706.313
2.95E-03	1.84E+00	61.362	0.565	61.927	1115.176	9.328	1124.504
4.72E-03	2.95E+00	98.179	0.565	98.744	1784.281	9.328	1793.609
7.56E-03	4.72E+00	157.086	0.565	157.651	2854.850	9.328	2864.178
1.00E-02	6.25E+00	207.902	0.565	208.467	3778.363	9.328	3787.691


1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01
1.0E-02
1.0E+04
1.0E+03
1.0E+02
1.0E+01
1.0E+00
1.0E-01
1.0E-02
Dose (rem)
50-rem
5-rem
1.0E-06
1.0E-05
1.0E-04
1.0E-03
1.0E-02
Airborne Release Fraction
Pu TEDE
TEDE Can
Pu (CDE+DDE)
CDE+DDE Can